



# **Article Quantifying the Impacts of COVID-19 Lockdown and Spring Festival on Air Quality over Yangtze River Delta Region**

Zeeshan Javed <sup>1,†</sup><sup>(b)</sup>, Aimon Tanvir <sup>2,†</sup>, Yuhang Wang <sup>3,\*</sup><sup>(b)</sup>, Ahmed Waqas <sup>4</sup>, Mingjie Xie <sup>1,\*</sup><sup>(b)</sup>, Adnan Abbas <sup>5</sup>, Osama Sandhu <sup>6</sup> and Cheng Liu <sup>7,8,9,10</sup>

- <sup>1</sup> Collaborative Innovation Center of Atmospheric Environment and Equipment Technology, Jiangsu Key Laboratory of Atmospheric Environment Monitoring and Pollution Control, School of Environmental Science and Engineering, Nanjing University of Information Science and Technology, Nanjing 210044, China; zeeshan@mail.ustc.edu.cn
- <sup>2</sup> Shanghai Key Laboratory of Atmospheric Particle Pollution and Prevention (LAP3), Department of Environmental Science and Engineering, Fudan University, Shanghai 200433, China; 19110740045@fudan.edu.cn
- <sup>3</sup> School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA 30332, USA
- <sup>4</sup> Division of Science and Technology, Department of Zoology, Multan Campus, University of Education, Lahore, Punjab 60700, Pakistan; ahmed.waqas@ue.edu.pk
- <sup>5</sup> Land Science Research Center, Nanjing University of Information Science & Technology, Nanjing 210044, China; adnanabbas@nuist.edu.cn
- <sup>6</sup> Pakistan Meteorological Department, Islamabad 44000, Pakistan; osamasandhu@pmd.gov.pk
  <sup>7</sup> Kay Laboratory of Procision Scientific Instrumentation of Aphysi Higher Education Institutes
  - Key Laboratory of Precision Scientific Instrumentation of Anhui Higher Education Institutes,
- University of Science and Technology of China, Hefei 230026, China; chliu81@ustc.edu.cn <sup>8</sup> Key Lab of Environmental Optics & Technology, Anhui Institute of Optics and Fine Mechanics,
  - Chinese Academy of Sciences, Hefei 230031, China
- Center for Excellence in Regional Atmospheric Environment, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China
- <sup>1</sup> Anhui Province Key Laboratory of Polar Environment and Global Change, University of Science and Technology of China, Hefei 230026, China
- Correspondence: ywang@eas.gatech.edu (Y.W.); mingjie.xie@nuist.edu.cn (M.X.)
- These authors contributed equally to this work.

**Abstract**: The emergence of the novel corona virus and the resulting lockdowns over various parts of the world have substantially impacted air quality due to reduced anthropogenic activity. The objective of this study is to investigate the impact of COVID-19 lockdown and Spring Festival on air quality of four major cities of Yangtze River Delta (YRD) region, including Shanghai, Nanjing, Hefei, and Hangzhou. In situ measurements were taken for nitrogen dioxide (NO<sub>2</sub>), particulate matter (PM<sub>2.5</sub>) and ozone (O<sub>3</sub>). In situ measurements from 1 January to 25 April were taken two years prior to COVID-19 (2018–19), during COVID-19 lockdown (2020), and one year after the COVID-19 (2021). The results indicated that the concentration of NO<sub>2</sub> and PM<sub>2.5</sub> dropped considerably during the lockdown days compared to normal days while the O<sub>3</sub> concentration showed an upsurge. The NO<sub>2</sub> showed reduction of about 54% on average during lockdown level 1 in 2020 whereas, PM 2.5 showed reduction of about 36% through the YRD. A substantial drop was observed in concentration of NO<sub>2</sub> during the Spring Festival holidays throughout the YRD from 2019 to 2021.

Keywords: YRD; COVID-19; lockdown; NO<sub>2</sub>; PM<sub>2.5</sub>; O<sub>3</sub>

## 1. Introduction

Severe acute respiratory syndrome coronavirus 2 (SARSCoV-2) is responsible for causing the novel coronavirus disease (COVID-19). The initial cases of the disease were reported on 1 December 2019 in the Chinese city of Wuhan in Hubei province [1]. This highly infectious virus quickly spread across the globe infecting millions of people. The infection generates mild symptoms of flu and common cold in most patients but can



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**Copyright:** © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). develop to serious respirational ailment in some cases. Thus, on 11 March 2020, World Health Organization categorized the disease as a global pandemic [1,2]. As of 14 April 2021, the number of people infected by coronavirus exceeded 13.6 million with over 2,941,128 deaths across the globe [3]. Therefore, the situation is termed as a global health crisis posing a huge challenge for the modern world [4]. Keeping in view the severity of the disease, the Chinese Government took substantial measures to contain the spread of virus by shutting down the industry and closing the educational and work-related institutions. The lockdown was implemented in two phases: Level 1 (24 January-26 February 2020) where strict measured were adopted to reduce mobility and Level-2 (27 February–31 March 2020) when the restrictions were relaxed to some extent [5]. This resulted in reduced mobility and significantly less anthropogenic activity that in turn led to a decrease in the anthropogenic emission of pollutants. Level-1 of the lockdown entailed complete closure of small and medium scale industries except for power plants and large enterprises. As a result of significant reduction in demand, the power production subsequently declined. Statistical data published by JiangSu Energy Regulatory Office (http://jsb.nea.gov.cn/, accessed on 27 April 2021) and Anhui Provincial Bureau of Statistics (http://tjj.ah.gov.cn/, accessed on 27 April 2021) depicted that the provinces showed a decline in electricity generation. The observed decline was 19% and 18% during January-February 2020 in Anhui and Jiagnsu, respectively, while it peaked during February reaching 27% and 26%, respectively compared to the same period in 2019. No major change was observed in the manufacturing sector and the statistics over the YRD provinces showed that production of medical and pharmaceuticals as well as iron and non-ferrous materials roughly remained the same. Construction, petrochemical, and facility manufacturing industries were strongly hit, and their operations were largely hindered. As a result of the supply chain movements, all other industries were carried to a halt. A sharp decline of 29% and 32% in industrial electricity consumption was observed in Anhui and Zhejiang provinces during the COVID-19 lockdown. Various studies conducted across the globe to explain the impact of COVID-19 lockdowns reported reductions in the levels of atmospheric trace gas species during the lockdown periods [5-12].

Increased level of atmospheric pollutants and trace gases over China has resulted from rapid economic sprawl [13]. Yangtze River Delta (YRD) region is notorious for its industrial and economic growth as well as high population density. These factors deem the region prone to atmospheric pollutant emissions resulting from industrial growth and anthropogenic activities enhancing pollution concerns [14] particularly during the winter months when meteorological conditions favor persistent air pollution episodes compared to other seasons [15]. Nitrogen dioxide  $(NO_2)$  is one of the key criteria pollutants in the atmosphere. This species plays a key role in atmospheric chemical processes, thereby strongly impacting air quality [16].  $NO_2$  acts a precursor for the formation of secondary organic aerosols (SOAs) and acts a crucial component of catalytic cycles leading to ozone  $(O_3)$  formation in the troposphere [17,18], consequently playing a key role in varying tropospheric chemistry [19]. The tropospheric emissions of this gas majorly come from fossil fuel combustion, biomass burning, soil and natural lightening [20]. The predominant source of NOx in urban areas is the emissions from anthropogenic activities including industrial processes, vehicle emissions, and power generation. Owing to its short life span in the lower troposphere (of the order of few hours), NOx is usually concentrated near to its sources [21]. Haze and photochemical smog result from the excessive  $NO_2$  and its chemical and photochemical interactions in the atmosphere [22]. Exposure to  $NO_2$  can increase the risk and incidence of respiratory system infections and may lead to asthma if prolonged [19]. Particulate matter (PM<sub>2.5</sub>) in the atmosphere are potentially damaging to human health by acting as a source of several respiratory and cardiovascular diseases. It mainly originates from urban activities like fuel combustion, vehicle exhausts, dust, and secondary sulphates [23]. PM<sub>2.5</sub> is linked to reduced tropospheric visibility and traffic induced  $PM_{2,5}$  is counted as the largest source for haze formation [24]. O<sub>3</sub> is an important and unique triatomic molecule of oxygen whose stratospheric concentration is crucial towards the survival of life on earth. However, tropospheric  $O_3$  is potentially damaging to humans and is a major deteriorating factor of air quality in urban areas. In situ reactions and transport from the stratosphere contribute to tropospheric ozone pollution [25].

Spring Festival is considered as the most significant holiday in China that marks the start of new lunar year when people move to their hometowns to celebrate holidays with their family. Thus, the Chinese New Year exodus is regarded among the world's largest annual migration. Owing to the closing of almost all institutions and industries, the anthropogenic activities are significantly reduced during Spring Festival holidays. [5]. The objective of the study is to summarize the impact of COVID-19 lockdown and Spring Festival on the criteria pollutants including  $NO_2$ ,  $PM_2$ , and  $O_2$  over YRD region. In situ measurements from 1 January to 25 April were taken two years prior to COVID-19 (2018–19), during COVID-19 lockdown (2020), and one year after the COVID-19 (2021). We studied the impact of Spring Festival holidays and COVID-19 lockdown by categorizing the study period into distinct phases. For Spring festival, the days were categorized as pre-Spring, Spring Festival, and post-Spring while for lockdown, the two levels of lockdown were considered (Level-1 and Level-2) along with the pre and post lockdown conditions. During Level-1 of the lockdown, the government adopted 1st level response to the pandemic by restricting all the activities while for Level-2, 2nd level response was adopted with some relaxations. Overall, the study tries to explain the impact of COVID-19 lockdown on the levels of criteria pollutants over YRD region while considering the reduction in anthropogenic activity as the major determinant.

#### 2. Materials and Methods

#### 2.1. Study Area

YRD region which includes Anhui, Jiangsu, Shanghai, and Zhejiang province is located on the eastern part of Yangtze Plain. The region has a fertile soil producing a variety of crops including cotton, grains, and hemp. As of 2018, the GDP of the region amounted USD 2.2 trillion (China Statistics: http://data.stats.gov.cn/english, accessed on 26 April 2021). The region spans over an area of 210,700 km<sup>2</sup>, with a population of about 0.23 billion in 2018 [26]. Owing to high population density, industrial and economic engagements, and anthropogenic activities, YRD region is prone to excessive pollution. This study has been conducted over four major cities of YRD region including Shanghai, Nanjing, Hefei, and Hangzhou, which are highly populated. These urban centers are the hubs for economic growth and industrial activity thereby vulnerable to excessive environmental pollution. Figure 1 shows the study region.

#### 2.2. Data Acquisition

In situ measurements for the criteria pollutants including NO<sub>2</sub>, PM<sub>2.5</sub>, and O<sub>3</sub> were obtained from online air quality analysis and monitoring platform of China National Environmental Monitoring Center (available online: http://106.37.208.233:20035/, accessed on 26 April 2021). The sampling sites selected for obtaining measurements were at the urban areas of Hefei, Shanghai, Nanjing, and China. The daily mean concentration of these measurements spanning from 1 January to 25 April 2018 to 2021 were used in this study.

#### 2.3. Meteorology Data

The hourly meteorological parameters (temperature, relative humidity, and wind speed) data was obtained from automatic weather stations installed at the airports of Hefei, Hangzhou, Nanjing, and Shanghai.



Figure 1. (A) The People's Republic of China map showing the location of (B) the Yangtze River Delta region.

#### 3. Results

The data spans over about four months (1 January to 25 April) for four consecutive years (2018–2021). COVID-19 lockdown measures were taken for the year 2020. The data has been categorized into four distinct phases corresponding to pre-lockdown (1 January–23 January), Level-1 (24 January–26 February), Level-2 (27 February–31 March), and post-lockdown (1 April–25 April). Although, lockdown scenario was not observed prior to or after 2020, the data categorization for the study has been kept the same to make comparison easier. The meteorological data for our study period showed that there was no noticeable change in terms of mean temperature, wind speed, and relative humidity during 2020 as compared to other years. However, the mean temperature is slightly higher in 2020 and 2021. Table 1 shows the mean value of different meteorological parameters in different years from 1 January to 25 April.

#### 3.1. NO<sub>2</sub>

The time series of daily mean NO<sub>2</sub> concentration over the cities of Hangzhou, Hefei, Shanghai, and Nanjing is developed. Figure 2 shows NO<sub>2</sub> time series over YRD region cities. It is quite evident from the data that the average concentration of NO<sub>2</sub> over these cities dropped during end of January 2020 compared to preceding and succeeding years. Several studies have reported the decrease in tropospheric NO<sub>2</sub> emissions over different parts of the world during the COVID-19 lockdown [5–12].

Parameters	Hangzhou			Hefei				Nanjing			Shanghai					
Year	2018	2019	2020	2021	2018	2019	2020	2021	2018	2019	2020	2021	2018	2019	2020	2021
Mean Temperature (°C)	10.17	10.40	11.18	11.48	8.89	8.50	9.08	9.50	8.74	9.25	10.1	10.16	9.31	9.86	10.84	10.35
Mean Wind speed (m/s)	8.62	7.60	7.97	8.06	7.80	8.96	9.51	9.80	9.71	8.45	9.26	9.86	9.68	8.92	9.40	8.91
Mean Relative Humidity (%)	71.41	77.33	72.16	68.60	72.09	78.28	78.90	70.37	78.23	73.32	80.90	71.23	70.15	75.18	71.13	71.15

 Table 1. Mean values of meteorological parameters (1 January to 25 April) at typical cities in YRD region.



Figure 2. Time series of daily averaged NO<sub>2</sub> over major cities of the YRD region.

Table 2 shows percentage change in  $NO_2$  over different cities for Level-1 and Level-2 compared to the pre-lockdown days from 2018 to 2021 where negative sign indicates reduction while positive shows increase in concentration. It is evident that the concentration of  $NO_2$  is considerably lower during Level 1 of the lockdown during 2020 as compared to other years. This phenomenon is observed in all the cities which correspond to significantly reduced anthropogenic activity during lockdown Level 1.

Cities	Year	Level-1(% Change)	Level-2(% Change)
Shanghai	2018	-13	-24
0	2019	-41	-15
	2020	-47	-35
	2021	-34	-27
Nanjing	2018	-24	-20
	2019	-35	-12
	2020	-51	-23
	2021	-41	-25
Hefei	2018	-20	-19
	2019	-35	-10
	2020	-54	-27
	2021	-41	-28
Hangzhou	2018	-23	-18
	2019	-40	-43
	2020	-66	-13
	2021	-44	-22

**Table 2.** Percentage change in mean NO<sub>2</sub> during lockdown levels (Level-1 (24 January–26 February) and Level-2 (27 February–31 March)) with reference to Pre-lockdown Phase (1 January–23 January).

### 3.2. PM<sub>2.5</sub>

Figure 3 shows the timeseries of  $PM_{2.5}$  at the studied cities. The results indicated that the levels of  $PM_{2.5}$  considerably dropped during 2020 compared to 2018, 2019, and 2021 that likely results as a consequence of the reduced anthropogenic activities, as explained in the introduction section.

Table 3 shows percentage change in  $PM_{2.5}$  over different cities for Level-1 and Level-2 compared to the pre-lockdown days from 2018 to 2021 where negative sign indicates reduction while positive shows increase in concentration. The average drop in the levels of  $PM_{2.5}$  during Level 1 is highest for 2020 when the lockdown was observed compared to other years. The reductions in  $PM_{2.5}$  during the COVID-19 lockdown has been reported in several studies [7,9,12,27].

**Table 3.** Percentage change in mean PM<sub>2.5</sub> during lockdown levels (Level-1 (24 January–26 February), Level-2 (27 February–31 March)) with reference to Pre-lockdown Phase (1 January–23 January).

Cities	Year	Level-1(% Change)	Level-2(% Change)
Shanghai	2018	-4	-26
0	2019	-30	-09
	2020	-36	-52
	2021	-27	-10
Nanjing	2018	-22	-43
	2019	-26	-31
	2020	-40	-50
	2021	-10	-21

Cities	Year	Level-1(% Change)	Level-2(% Change)
Hefei	2018	-23	-48
	2019	-23	-39
	2020	-39	-48
	2021	-20	-27
Hangzhou	2018	-2	-34
Ũ	2019	-21	-31

-33

-23

 Table 3. Cont.



2020

2021

Figure 3. Time series of daily averaged  $PM_{2.5}$  over the studied cities.

-42

-39

# 3.3. O<sub>3</sub>

The trend in  $O_3$  concentration is opposite to that of other atmospheric pollutants. There is no impact of COVID-19 Lockdown on level of tropospheric  $O_3$ . This has been depicted by the time series in Figure 4.



Figure 4. Time series for daily averaged O<sub>3</sub> over the studied cities.

It is evident that the lockdown and reduction in anthropogenic activity during 2020 had reciprocal effect on  $O_3$  concentration. On average, the concentration is lower during the period preceding the lockdown. Several studies have reported an increase in  $O_3$  concentration with reduction in anthropogenic activity during the lockdown period [5,6,11,12].

Table 4 shows the percent change in  $O_3$  over the studied months for different years categorized into distinct phases where negative sign indicates reduction while positive shows increase in concentration.

**Table 4.** Percentage change in mean O<sub>3</sub> during lockdown levels (Level-1(24 January–26 February) and Level-2 (27 February–31 March)) with reference to Pre-lockdown Phase (1 January–23 January).

Cities	Year	Level-1(% Change)	Level-2(% Change)
Shanghai	2018	38	69
Ŭ	2019	26	71
	2020	45	60
	2021	41	50
Nanjing	2018	43	86
	2019	60	130
	2020	77	95
	2021	43	60
Hefei	2018	46	80
	2019	39	119
	2020	108	113
	2021	47	79
Hangzhou	2018	2	34
-	2019	21	31
	2020	33	42
	2021	23	39

#### 3.4. Spring Festival and Air Quality

The Spring Festival is the highly valuable vacation for the Chinese people, and it usually includes family gatherings. Many migrant residents return to their hometowns to celebrate the Festival with their families, which is particularly noticeable in China's megacities. Factory closures and a large reduction in vehicle numbers are common during the Festival, resulting in a significant reduction in air pollution. To assess the effect of the Spring Festival on NO<sub>2</sub> and PM<sub>2.5</sub> concentration over different cities of YRD region, we grouped the observation period into three, Pre-Spring Festival, Spring Festival, and post Spring Festival. Table 5 shows the categories.

Table 5. Study period for spring festival during different years.

Year	Pre-Spring Festival	Spring Festival	<b>Post-Spring Festival</b>
2019	28 January–3 February	4 February–10 February	11 February–17 February
2020	18 January–24 January	25 January–31 January	1 February–7 February
2021	4 February–10 February	11 February–17 February	18 February–24 February

Figure 5 shows impact of spring festival on  $NO_2$  concentration over different cities of YRD region of China. There is notable reduction in concentration of  $NO_2$  during spring festival. Owing to the closing of almost all institutions and industries, the anthropogenic activities are considerably reduced during Spring Festival holidays whereas  $NO_2$  is mainly produced from anthropogenic sources.



Figure 5. Impact of Spring Festival holidays on the NO<sub>2</sub> concentration over YRD region.

# 4. Discussion

Pollutant distribution over a locality is affected by the residence time and chemical behavior of the species which are determined by the meteorological conditions. Ample evidence has been found in literature linking meteorological factors with aerosol and trace gas distribution [16]. A dynamic and multidimensional understanding of the atmosphere is possible by considering the trace gas sources, sinks and their mutual interactions along

with certain meteorological parameters that may impact these interactions. For the current study, the meteorological conditions over the region as reported in different cities of YRD region have been found the same for the study period thereby eliminating the chance of the impact of meteorology on trace gas concentration during the lockdown period. The average temperature and wind speed are almost similar from 2017 to 2020 [19].

The closing of industry, offices, and educational institutions resulting in reduced mobility and lowering the anthropogenic activity has significant impact on the daily mean concentration of tropospheric trace gas species, this study has considered the COVID-19 lockdown period and Spring Festival holidays where human activities came to a halt. The average  $NO_2$  and  $PM_{25}$  measurement is considerably lower for all the cities during lockdown for the year 2020 compared to 2018, 2019 and 2021. For Shanghai, the NO<sub>2</sub> measurements show a change of -47% and -35% for Level-1 and Level-2 of the lockdown compared to the pre-lockdown scenario during 2020. A similar trend was observed for other cities reporting -51% and -23% for Nanjing. The trend was -54% and -27% for Hefei and -66% and -13% for Hangzhou during Level-1 and Level-2 of the lockdown, respectively. It is important to mention that NO<sub>2</sub> concentration also shows reduction to some extent during level 1 and level 2 in pre COVID years (2018 and 2019) and post COVID year (2021). This phenomenon can be attributed to the fact that the seasonal cycle of NO<sub>2</sub> shows maxima during winter and a minimum during summer. Therefore, a drop is observed moving from January to April owing to seasonality, which is evident during the years when no lockdown was observed. However, this drop in concentration is much higher in the 2020 COVID year.

 $PM_{2.5}$  followed the same trend with change of -36% and -52% for Shanghai, -33% and -45%, for Nanjing, -39% and -48% for Hefei and -33% and -42% for Hangzhou during 2020.

The results indicated a higher reduction in tropospheric NO<sub>2</sub> measurements as an affirmation that this species majorly emerges from anthropogenic sources. The results showed that NO<sub>2</sub> concentration is notably reduced during spring festival through all the cities of China. The ministry of transport for People's Republic of China reported a reduction by about 50% in overall traffic load during 2020 Annual Spring Festival compared to the preceding and succeeding years (available online: http://www.mot.gov.cn/ accessed on 25 April 2021). Various studies have reported a reduction in the atmospheric trace gas concentration during the Spring Festival holidays over various parts of China [28–31].

The level of  $O_3$  in the atmosphere was not impacted by the lockdown or change in anthropogenic activity and kept on rising during the study period while the solar radiation intensified for late winter and early spring days [5,6].  $O_3$  measurements show notable rise in concentration during lockdown compared to pre lockdown days depicting 45% and 60% for Shanghai, 100% and 136 for Nanjing, 108% and 113% for Hefei, and 33% and 42% for Hangzhou for Level-1 and Level-2 of the COVID-19 lockdown, respectively. The average increase in  $O_3$  is higher during 2020 compared to the same period during preceding and succeeding years.

This study concludes that  $NO_2$  concentration drops considerably during COVID 19 lockdown, PM <sub>2.5</sub> also showed some drop in level during lockdown phases. While  $O_3$  levels do not have any effect of COVID 19 lockdown. This indicates it is tough to control level of  $O_3$  in YRD region. The more efforts and measures should be put forward to control air pollution in YRD region.

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